AD-A045 917 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 17/2

OPTICAL TELECOMMUNICATION PATHS (LINES), (U)

MAR 77 H KLEJMAN

UNCLASSIFIED FTD-ID(RS)I-0034-77 NL

1 OF 1

ADA

045917

END

DATE

FILMED

11-77

DDC

FTD-ID(RS)I-0034-77

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

OPTICAL TELECOMMUNICATION PATHS (LINES)

by

H. Klejman

FOREIGN TECHNOLOGY DIVISION

FTD- ID(RS)I-0034-77

EDITED TRANSLATION

FTD-ID(RS)I-0034-77 15 March 1977

FTD-77-C-000248

OPTICAL TELECOMMUNICATION PATHS (LINES)

By: H. Klejman

English pages: 13

Source: Prezeglad Telekomunikacyjny, Nr 6, 1976, PP. 173-176.

Country of origin: POLAND
Translated by: LINGUISTIC SYSTEMS, INC.
F33657-76-D-0389
W. J. Whelan
Requester: FTD/ETDO

Approved for public release; distribution unlimited.

ACCESSION for
NTIS White Section X
DDC Buff Section
UNANNOUNCED
JUSTIFICATION

BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

OPTICAL TELECOMMUNICATION PATHS (LINES)

Herman Klejman

The optical way of sending thru (transmitting) information has in general a multi-century history. Limiting ourselves to its modern parts, one can state that the first tests of optical communication were carried on at the end of the eigtheenth century, when there was built in France (in accordance with the Chappe bros[1] construction), a semaphore "telegraph" line connecting Paris with Lille. On a section of length 210 km there were distributed at that time 20 relay stations (towers). In the year 1839 there was completed the building of an optical communication line between Petersburg and Warsaw. Its length amounted to 1200 km and along it there were set up as many as 149 intermediate stations - each with a two person team, the signalman - transmitting signals, as well as an operator - receiving and writing down the contents of the dispatches. The time necessary for the transmitting of the first dispatch, complicated by the 45 signals of the French system, from Petersburg to Warsaw, amounted to 22 minutes. From the middle of the preceeding century there went forward also experiments and tests, in the field of telegraph and later also of telephone optical communication, that is, the sending and receiving of light signals handled by morse's symbols, or modulated by sound.

In the period that preceded the introduction of electrical telecommunication, optical communication was the fastest and most efficient way of reaching agreement over even very great distances. The development of the telegraph and telephone, guided and later unguided, pushed aside plans for the problem of optical communication. Only in special application, especially military, did communication on light waves in the infrared area maintain a certain importance (for instance in the course of the second world war optical telephone used to be used for communication over a range of from 3 to 15 km).

The invention of the laser (in the year 1960) gave a powerful impulse to the renewal of investigations and experiments in the field of optical telecommunication, and the unattainable-to-this-time properties provided by the laser, of a light beam, (coherence, monochromaticity, and minimum divergence) dazzled the scientists and engineers abruptly by their dazzling prospects. Then it was nothing strange that arising after the year 1960 numerous investigational systems, operating on the development and exploitation of lasers, directed their efforts to an important extent on the application of a laser beam for communication purposes.

Optical Path in Cosmic Space

The basic advantage of a laser beam that constitutes an optical telecommunication path, is the possibility of attaining - thanks to the special coherence of the laser light - of an unusually small divergence, measured by an angle which reaches as much as one second during the use of a suitable optical system at the output of the laser (this corresponds to a rough increase of the diameter of the beam of barely 5 mm over a path of length 1 km). The level of collimation of the light beam can thus be in this example very high - limited in theory by the phenomenon of diffraction[2], and in practice by the difficulties of working out,

with the necessary precision, of an optical system of relatively large dimensions (with regard to the required magnitude of the aperture).

One uses here the word "relatively," having in mind a comparison of the dimensions of the optical system at the output of the laser - which fulfills de facto the role of a transmitting antenna system - with the length of the light wave emitted thru it, measured in micrometers or in a fraction of a micrometer. This ratio is unusually advantageous - from the point of view of obtaining a narrow characteristic of the directed radiation - in comparison with antenna systems for the microwave range, used for instance in radio lines (even with the use of an extreme band of frequencies in this range).

The discussed property of a laser telecommunication path has an especially important significance for cosmis communication (also for location telemetry and similar), which (communication) requires from the nature of the thing huge ranges of operation. There favor the attainment of such ranges the perfect conditions of propagation of light radiation in cosmic space, where their absorbtion does not occur, nor their dispersion nor refraction as happens in the earth's atmosphere.

What is more - in cosmic space one can make the angle of divergence of the beam of coherent light still smaller than the above mentioned limit of one inch, dictated by the unfavorable influence of the phenomenon of refraction in the atmosphere. For instance Prof. C. H. Townes in his theoretical considerations [2] on the topic of prospects for communication at cosmic distances, establishes the angle of divergence of the laser beam at 10^{-7} radians (0.02"). In order to obtain so small a divergence of the beam Townes in his calculations establishes that the radiation of the laser (of wavelength 0.5 μm) gets directed - with the help of a diverging lens - onto a very large converging lens of diameter

5 m in such a way as to illuminate its whole surface coherently and more or less uniformly. Such an almost ideal parallelness of the beam, one can - as was said - attain only beyond the atmosphere of the earth[3]).

Optical Path in the Atmosphere

The propagation of a light beam under conditions on earth is powerfully made difficult as a result of absorbtion, dispersion, and refraction of the light radiation in the atmosphere, especially under the influnece of such factors as mist, rain, snow, smoke, dust, whirling (turbulence) of the air, and similar. Even fully clean and ideally quiet air absorbs and disperses a certain amount of the energy of a beam passing thru it.

The attenuation (extinction) of radiation in the atmosphere is a result of the simultaneously appearing phenomena of absorbtion and dispersion, whereby the portion of each of these phenomena can be different at a level dependent on the state of the atmosphere (on meteorological conditions, the altitude, the type and concentraion of suspended materials, and similar) as well as on the length of the light waves. The propagation of a beam of radiation in the atmosphere can be characterized by the equation:

$$I=I_0 \exp(-a_e l) \qquad (1)$$

in which:

I_0 - is the intensity of radiation at the beginning of the path ($l=0$),

l - is the length of the path pierced in the atmosphere,

I - is the intensity of the radiation at the end of the path l,

a_e - is the coefficient of attenuation.

In accordance with what has previously been formulated

$$a_e=a_a+a_d \qquad (2)$$

From equation (1) there results that the transmission of the radiation

$$T=\frac{I}{I_0}=e^{-a_e l} \quad (3)$$

The coefficients a_a and a_d depend in an extremely complicated manner on the wavelength, which is represented by the multiplicity and complication of the factors influencing the attenuation of radiation. Figure 1 illustrates this on which there is presented the spectral characteristic of the atmospheric permeability near earth, measured for three large sections of the optical range in different parts of the day and with different lengths of the path of propagation of the light beam [3]. As is apparent from the ranges, the dependence of the level of transparency of the atmosphere on the wavelength is very great: the curves are irregular, "mangled," have many peaks, that correspond to the so-called "windows" of atmospheric permeability, and many deep valleys in which the attenuation of the light is especially great. The lower layer of the atmosphere is thus for optical radiation a selective filter of very complicated action, of very uneven weakening, depending on many variable factors in time and space.

One can however separate out a number of wave bands in which the air lets thru light radiation significantly better than in the remaining sections of the optical spectrum. They are for instance the bands: 0.5-0.9 μm, 1.0-1.1 μm, 1.2-1.3 μm, 1.55-1.75 μm, 2.1-2.4 μm, 3.4-4.1 μm, as well as 8-12.5 μm. The existence of these bands in the atmosphere makes possible telecommunication on "air" optical paths. In this regard there gains special significance the last distinguished pass-band (8-12.5 μm) from the point of view of the successful development of molecular lasers [4] which generate radiation of great power with a wavelength 10.6 μm, especially advantageous for purposes of communication since it is relatively weakly attenuated in the atmosphere[4].

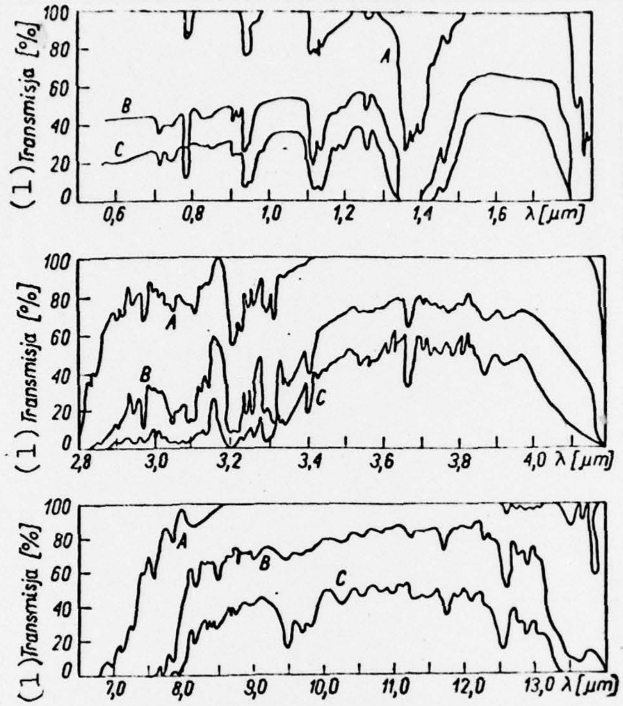

Figure 1. Spectral characteristic of the transmission of radiation of lasers in the near-earth atmosphere (in a horizontal (level) direction): curve A - length of the path of the beam 0.3 km, humidity of the air 62%, time of day 1500 hours; curve B - length of the path of the beam 5.5 km, humidity of the air 47%, time of day 2200 hours; curve C - length of the path of the beam, 16 km, humidity of the air 48%, time of day 1200 hours.
Key: (1) Transmission.

As the altitude increases the attenuation of the light decreases and at altitudes of 60-70 km one can disregard it. In the near-earth layer of the atmosphere, roughly up to altitudes of 10-12 km, there fulfill a main role in the absorbtion of optical radiation molecules of water vapor and carbon dioxide.

The concentration of water vapor in the atmosphere varies within broad limits 0.001-4% (volumewise); it depends on many factors: on the temperature and the humidity of the air, the geographical situation (location), the time of year, on local meteorological conditions, etc. With an increase of the altitude this concentration to a significant extent decreases due to the distance from the evaporating surface, as well as to the process of

condensation which appears as a result of the lowering of the temperature.

The content of carbon dioxide in the air varies within the limits 0.03-0.05%, where the upper limit corresponds to urban centers. At high altitudes (around 30 km) ozone has a relatively significant influence on the absorbtion of radiation, the concentration of which (ozone) amounts here to above 0.001%, while at lower levels of the atmosphere it is two to three times less in magnitude.

A clearly unfavorable influence on the propagation of a light beam in the atmosphere is had by snowfalls or rainfalls as well as the so-called aerosols, or suspensions in the air of very small liquid bodies (mist, clouds) or of solids (smoke, dust, crystals of ice etc). At low altitudes the main reason for polution of the atmosphere is smoke and dust. The number of dust particles in 1 cm^3 of air during dry clear weather does not exceed 100 at an altitude of 3000 m, however near the surface of the earth this number reaches 130,000 [5]. Rain decreases it to around 30,000, but above the sea or a lake at a distance of for instance 20 km from the shore, the dustines of the atmosphere amounts already to around 1000 dust particles/cm^3. Over large cities there is obviously a lot of dust and smoke but these polution do not reach above 500-700 m.

A second element in the attenuation of a light beam in the atmosphere is the phenomenon of the scattering (dispersion) of light. This can be the so-called molecular dispersion, happening even in fully clean air, deprived of all suspended materials. Here we are dealing with the (inter) action of the light beam (photons) with molecules of gases contained in the atmosphere where these molecules are rather small in comparison with the wavelength. The intensity of this process depends to a significant degree on the wavelength - in agreement with Rayleigh's law. The law expresses with an exponential function the dependence of the intensity of

radiation on the path pierced by the light beam, where the coefficient of the scattering is inversely proportional to the fourth power of the wavelength. The intensity of the radiation occurring as a result of Rayleigh dispersion can be in the visual part of the spectrum, significantly stronger than the previously mentioned molecular absorbtion. In the infrared range the molecular scattering is very weak.

Other kinds of dispersion - the so-called diffractive dispersion, when the dimensions of the molecules that scatter the light are commensurate with its wavelength, as well as geometrical dispersion when the dimensions of the molecules significantly exceed the length of the scattered light wave. We are then dealing with scattering on suspended materials (aerosols), whence there also comes the occasionally encountered name of aerosol dispersion [5]. The influence of this phenomenon on atmospheric permeability manifests itself in the whole optical range. Aerosol dispersion depends on the magnitude and concentration of the suspended materials, as well as on the shape of the molecules. Here atmospheric conditions have a deciding influence.

On Figure 2 [7] there are shown the ranges of an approximate dependance (functional relationship) of the coefficient of light transmission (light of wavelength 0.9 μm) on the state of the atmosphere characterized by the so-called visible visibility W[5)] - a relatively simple parameter to estimate under conditions of use. These ranges illustrate the powerful influence of atmospheric conditions on the propagation of a light wave. Even during good visible visibility (W=10 km) there arises a fourfold diminution of the intensity of the radiaiton at a distance of 8 km.

Besides the losses in the atmosphere caused by absorbtion and dispersion, an important complication for optical communication on the earth is also refraction of the light radiation brought about generally by the temperature gradient of the air. Even an

insignificant refraction of the radiation and the resulting from it variations in the angle of incidence of the beam falling on the receiver can interfere with communication of its divergence is so small as in the case of a laser beam. Air turbulences also influence the laser light at a more powerful level than on ordinary incoherent light, causing a phase interference with the phase uniformity of the front of the light wave as well as undesired changes in the signal level (additional modulation and hence troubles during reception).

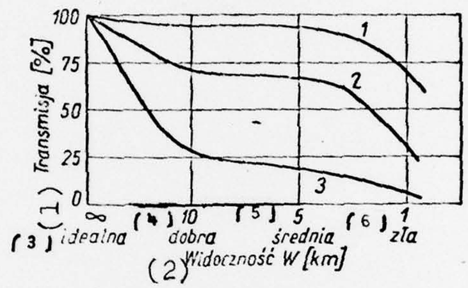

Figure 2. Dependence of the light transmission on the state of visibility of the atmosphere: Curve 1 - for a distance of 200 m; curve 2 - for a distance of 1 km; curve 3 - for a distance of 8 km.
Key: (1) Transmission; (2) Visibility; (3) ideal; (4) good; (5) average; (6) bad.

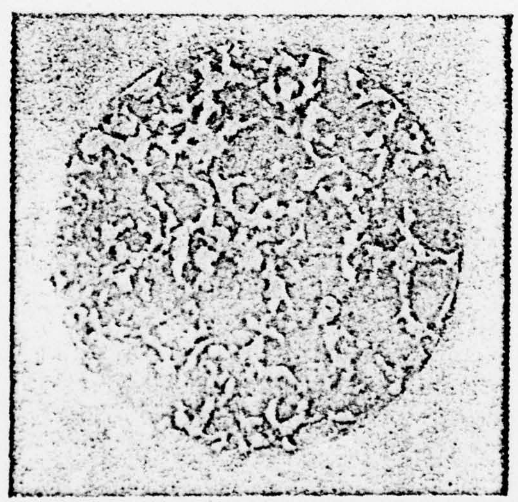

Figure 3. Cross section of a laser beam going thru a turbulent air medium.

Such phenomena appear especially in the near-to-ground layer of air especially on sunny days when the earth is powerfully heated up. This causes intensive turbulences (undulations and whirlings) in the air surrounding it (the earth). It gets optically non-uniform whereby the temperatures of individual air spaces (and thus also the coefficients of refraction) change in a chaotic manner in time and space. Optical non-uniformities - of dimensions less than the diameter of the beam - cause fluctuations in the intensity of the light in its cross section (called scinillations) as a result of diffraction-interference effects, arising during the passing of the laser beam thru the turbulent air medium. The cross-section of such a beam is shown on Figure 3 [8].

Optical Path in a Water Medium

The propagation of an optical beam in water is based on a basically similar law as is the propagation of light radiation in the atmosphere. Analogously thus the components of attenuation introduced by the water medium are: the absorbtion of the energy of the beam and its scattering in the water. Important also in this case are the equations (1-3), which have to do with the coefficients of extinction, absorbtion, and dispersion cited above for the air medium. The amount of the attenuation of light in water is, obviously significantly greater than in the atmosphere.

Absorbtion in the water medium is caused mainly by water molecules and substances dispersed in it, but the scattering of light radiation is caused by suspended materials, air blisters, and similar. Depending on the type of water medium the influence of absorbtion is commensurate with - (small) fraction of scattering or else exceeds - to a more or less extent - one of these components of attenuation of the beam. In transparent water there arises most powerfully the process of absorbtion but in murky water the phenomenon of dispersion plays the main role.

Just as in the atmosphere the attenuation of light radiation propagating itself in a water medium depends on the wavelength of this radiation. In numerous experiments and tests there results that the best conditions in general for propagation in water exist in the green-blue part of the spectrum.

For clear water the minimum value of the coefficient of attenuation is observed at wavelengths that lie in the range 0.5-0.55 μm. Moreover for murky water or for chemical solutions the minimum attenuation occurs at somewhat long wave (lengths), in the neighborhood of 0.6 μm. The dependence of the coefficient of attenuation on the length of the light wave stands out in a fully clear way for a given medium. For instance - within the limits of the visual range the attenuation of the radiation can change in 13-19 or even 30-90 proportions - under the same propagation conditions.

Measurements of the coefficient of attenuation in water are difficult. They are accomplished by means of measurements of the range of underwater communication, on which (range) this coefficient has the greatest influence. For example - the results of this type of measurements performed in lake crater (the water in this lake is very clear), are set up below.

λ [μm]	0.35	0.42	0.45	0.5	0.6
a_e [1/m]	0.049	0.0158	0.0201	0.0324	0.223
Range [m]	775	2400	1900	1165	170

The coefficient of attenuation increases with an increase in the depth of the water container. Thus for instance at a depth of 7.8 m there was measured a_e=0.06 (range 635 m) but at a depth of 16.9 m the coefficient a_e=0.09 (range 423 m) for a wavelength of λ=0.5 μm.

Investigations of the propagation properties of various water areas, especially sea and ocean, have a major significance for communication and underwater location, equally for military and even civilian purposes.

Light Guide Paths

In order to avoid the unfavorable influence of low levels of the atmosphere on the propagation of light radiation, there have been carried out successful tests on the application of light waveguides or lightguides that is, of a special guide guiding the beam of radiation from the transmitter to the receiving point and shielding it from the harmful influences of the atmosphere. There is produced in this way a closed system for guiding light separated from the environment and controlled at a level that guarantees a suitable stability of the optical telecommunication path. Such a path takes the form of a beam of radiation propagating itself in a specially-prepared-for-this-purpose transparent medium.

Investigations and experimental works in the sphere of telecommunication with light along light-guide paths (mainly - with the application of glass fibers) have developed much in late years. Opinion in the world is in agreement attributing to this type of telecommunication great significance and important applications in the near future. It is worthwhile thus to devote to lightguides a separate article in one of the next issues of PT (Przeglad Telekomunicyjny = Telecommunications Review).

Footnotes

1) This was a very primitive construction: three beams placed on a mast on a special tower and lifted by a crane (jack), arranged into certain symbols corresponding to the individual letters or numbers [1].

2) The limiting angle of the divergence is computed from the approximate relationship $\Theta \approx 1.22\ \lambda/D$, where λ - the length of the wave of coherent radiation, D - the diameter of the aperture of the optical system.

3) Experiments of this type should thus be carried on, not on the surface of the earth, but from the deck of a large station - laboratory, placed in an orbit around the earth, or - still better - from the surface of the moon, the advantages of which are undeniable as those of a perfect astronomical observatory (speaking parenthetically) - the projected foundations of a moon laboratory were discussed at the International Astronautical Congress in Warsaw in the year 1964, that is five years before the first landing of the first astronauts on the silver sphere.

4) The difficulty here lies mainly in the selection of suitable elements necessary for the building of a laser hookup; this concerns especially the photodetector from the point of view of its small sensitivity in this band of infrared radiation.

5) The "visual visibility" is determined ordinarily as the distance at which the contrast in relation to a black background (produced by a black object placed in a level plane) falls at 2%. It is thus the distance that corresponds to a light attenuation of 17 dB. For example - if a hill separated by 10 km ceases to be visible, this means that the attenuation of the layer of atmosphere that separates it from the observer amounts to 1.7 dB/km.

Literature

1. Praca zbiorowa: 400 lat Poczty Polskiej. Wydawnictwa Komunikacyjne, Warszawa 1958.
2. *Townes C. H.:* Niekotoryje primienienija genieratorow opticzieskowo i infrakrasnowo diapazonow. Przekład rosyjski ze zbioru: Advances in Quantum Electronics, I. R. Singer, New York — London, 1961 (zamieszczony w zbiorze: Łazery. Izdatielstwo Inostrannoj Litieratury, Moskwa 1963).
3. *Czernyszew W. N., Szeremietiew A. G., Kobziew W. W.:* Łazery w sistiemach swiazi. Swiaż, Moskwa 1966.
4. *Klejman H.:* Lasery. PWN, Warszawa 1974.
5. *Kobziew W. W., Milinkis B. M., Jemielianow P. G.:* Primienienie opticzieskich kwantowych genieratorow dla celej swiazi. Swiaż, Moskwa 1965.
6. *Muradian A. G.:* Perspektywy zastosowania optycznych linii łączności. Biuletyn Informacyjny SEP, nr 2, 1967, s. 50–64.
7. *Klejman H., Dzięciołowski K., Rzewuski M.:* Lasery w telekomunikacji. WNT, Warszawa 1970.
8. *Deitz P. H.:* Near-earth propagation of optical beams. Electronic Communicator, Vol. 2, No 5, 1967, s. 15.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FTD-ID(RS)I-0034-77	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) OPTICAL TELECOMMUNICATION PATHS (LINES)		5. TYPE OF REPORT & PERIOD COVERED Translation
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) H. Klejman		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Foreign Technology Division Air Force Systems Command U. S. Air Force		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 1976
		13. NUMBER OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) 17; 20		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
A205 DMATC	1
A210 DMAAC	2
B344 DIA/RDS-3C	8
C043 USAMIIA	1
C509 BALLISTIC RES LABS	1
C510 AIR MOBILITY R&D LAB/FIO	1
C513 PICATINNY ARSENAL	1
C535 AVIATION SYS COMD	1
C557 USAIIC	1
C591 FSTC	5
C619 MIA REDSTONE	1
D008 NISC	1
H300 USAICE (USAREUR)	1
P005 ERDA	2
P055 CIA/CRS/ADD/SD	1
NAVORDSTA (50L)	1
NAVWPNSCEN (Code 121)	1
NASA/KSI	1
544 IES/RDPO	1
AFIT/LD	1

ORGANIZATION	MICROFICHE
E053 AF/INAKA	1
E017 AF/ RDXTR-W	1
E404 AEDC	1
E408 AFWL	1
E410 ADTC	1
E413 ESD	2
FTD	
CCN	1
ETID	3
NIA/PHS	1
NICD	5